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## Experimental exploration of a novel chemisorption composite of SrCl<sub>2</sub>-NEG adding with Carbon coated Ni

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### Abstract

This study reports the development and experimental investigation on a novel chemisorption composite material by adding Carbon coated Ni into SrCl<sub>2</sub>-NEG. The manufacture processes on this novel material has been developed in order to control the evenly distribution of the Nano particles inside the composite. The sorption performance of the novel chemisorption composite using ammonia as the working fluid was experimentally tested and compared with the performance of conventional chemisorption composite without adding Carbon coated Ni. Results pointed out that compared with conventional chemisorption one (SrCl<sub>2</sub>/NEG) this novel developed composite requires less heat source energy but has relatively lower mass transfer performance. The overall efficiency of an adsorption system using this novel chemisorption composite as the adsorbent could be potentially improved and the overall cycle time can be reduced.

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Keywords: Carbon-coated Nickel, Strontium chloride, ammonia, adsorption/desorption performance, heat and mass transfer

### 1. Introduction

Solid gas sorption technology attracts ever increasing attentions to be used as refrigerator or heat pump due to high demand of alternative, effective and environmental friendly technologies for the recovery of wasted heat into useful energy since 1970s [1, 2]. Many researchers pointed out the importance of development and investigation on new adsorption materials to improve the overall system performance of adsorption cycles [3-8]. Compared with physical adsorbent, chemical adsorbent has the advantage of larger adsorption capacity, faster reaction speed and higher energy density, which can be potentially used in thermal energy storage system [5, 9]. However, the chemical adsorbents suffer from swelling and

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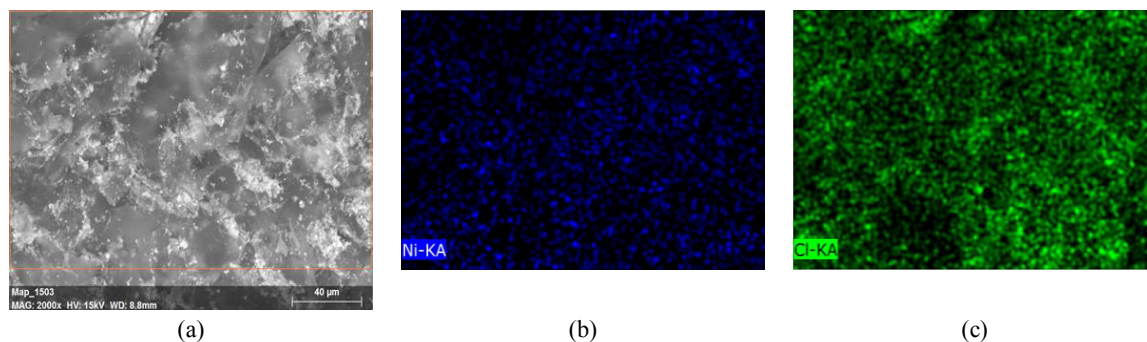
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agglomeration problems, which will reduce the heat and mass transfer performance of the adsorbents after several cycles[9]. Composite adsorbents were proposed and developed to solve these two problems[9]. Chlorides/porous media/ammonia apply porous media as the matrix to improve the heat/mass transfer of the chlorides salts. The most commonly used porous media includes expanded graphite[6], activated carbon[8] and activated carbon fibre[3]. The recent interests of nanotechnology may be a potential technology to boost the application of sorption technology and development of new composite adsorbents. Carbon coated Metal nanoparticles inherit several advantages of metal such as high thermal conductivity, high heat capacity and high electrical conductivity[10, 11]. In this study, Carbon coated Nickel (Ni@C) was used and added as an additive into Strontium Chloride/Natural Expanded Graphite to form a new composite adsorbent. The mixing processes were developed in order to ensure evenly distribution of nanoparticle and salt inside the composite. Moreover, the sorption performance of the composite adsorbent with and without Ni@C was experimentally tested and evaluated. The aim of this study is to explore the feasibility and effects of adding Ni@C into conventional chemisorption composite.

## 2. Experimental study and evaluation methods

### 2.1 Preparation of chemisorption composite

The novel chemisorption composite investigated in this study is a mixture of Strontium Chloride, Natural Expanded Graphite and Carbon coated Nickel. The uniformity of the nanoparticle inside the mixture is critical to control the quality of the composite and prove the feasibility of the idea of introducing Carbon coated Metal nanoparticle into chemisorption composite. The nanoparticle was first dispersed in ethanol with ultrasonic bath for 30 minutes to prevent the aggregation of Carbon coated Nickel during the mixture process. The mixture of Strontium Chloride and Natural expanded Graphite was then added into the suspension by ultrasonic treatment for another 30 minutes. The mixture of Strontium Chloride, Natural Expanded Graphite and Carbon coated Nickel was stirred during the drying process in an oven at 120 °C for 48 hours.



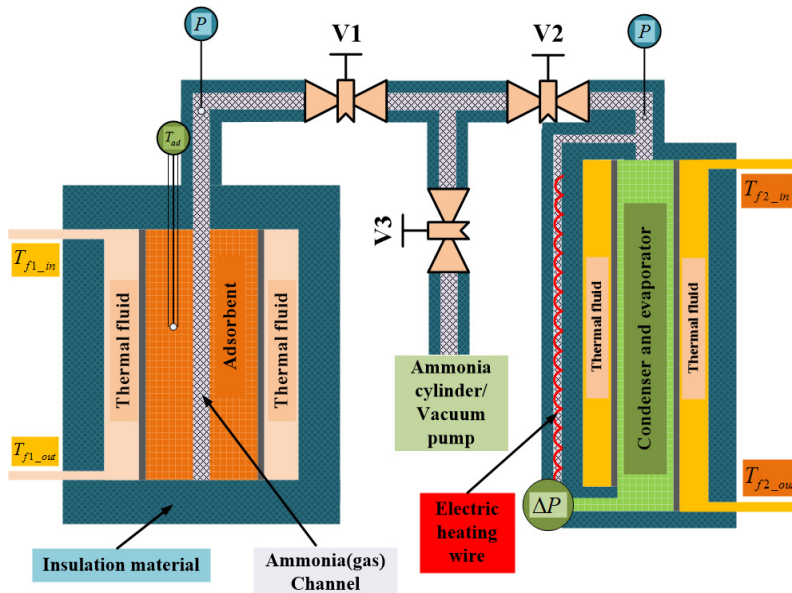
**Fig. 1.** SEM image and EDX Mapping of composite sample

(a) SEM image of the sample; (b) EDX Mapping of the element *Ni* ; (c) EDX Mapping of the element *Cl*

The chemisorption composite mixture of Natural Expanded Graphite, Strontium Chloride and Carbon coated Nickel was prepared with the weight ratio of 20:40:1. Prepared composite was scanned by a Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray spectroscopy (DEX) in order to observe the elements distribution of the composite. The SEM image of the sample illustrates the surface

morphology of the composite sample as shown in Figure 1 (a). The distribution of element *Ni* and *Cl* in the composite can be used to verify the uniformity of the nanoparticle and the salt. Although slight agglomeration of salt can be observed in Figure 1 (c), the overall distribution of Carbon coated Nickel and Strontium Chloride in the composite material are quite uniform as indicated in Figure 1 (b) and Figure 1 (c).

## 2.2 Description of the adsorption/desorption test rig



**Fig. 2.** Schematic diagram of the adsorption performance test bench [12]

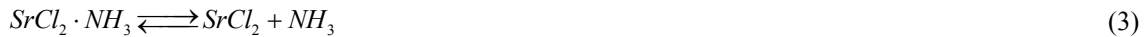
An adsorption performance test rig using volumetric testing method, which can test dynamic kinetics relationship between the adsorbent and ammonia, was designed, constructed and used to measure the sorption performance of the chemisorption composite. This test bench mainly includes an adsorbent bed, condenser/evaporator, two oil bath units, a differential pressure sensor, two pressure sensors, five temperature sensors, electric heating wire and some accessories as shown

in Figure 2. The description of desorption process can be used to explain the working principle of this rig. During desorption process, the adsorbent bed is heated by the thermal oil from the oil bath, while the temperature of the condenser/evaporator is controlled by a cryostat. The ammonia desorbs from the adsorbent and condenses in the condenser / evaporator. The differential pressure sensor is located on the bottom of the condenser / evaporator to measure the pressure difference between the top and bottom of the condenser / evaporator. The function of the electric heating wire is to ensure there is no liquid ammonia left in the pipe line on the left of the condenser / evaporator as indicated in Figure 2. The differential pressure sensor can therefore accurately monitor and record the pressure difference between the top and bottom of the condenser / evaporator.

The gross mass of the ammonia inside the condenser / evaporator can be calculated by equation (1) [12], where  $A_c$  and  $V$  is the internal area and internal volume of the condenser/evaporator, respectively.  $v_f(T_e)$  and  $v_g(T_e)$  is the specific volume of the saturated liquid and vapour phase ammonia under the controlled temperature  $T_e$  of the condenser / evaporator.

$$m_{am} = \left[1 - \frac{v_f(T_e)}{v_g(T_e)}\right] \cdot \frac{A_c}{g} \cdot \Delta p + \frac{V}{v_g(T_e)} \quad (1)$$

The chemical reaction equations between  $\text{SrCl}_2$  and  $\text{NH}_3$  including two steps, which can be written as equation (2) and (3).

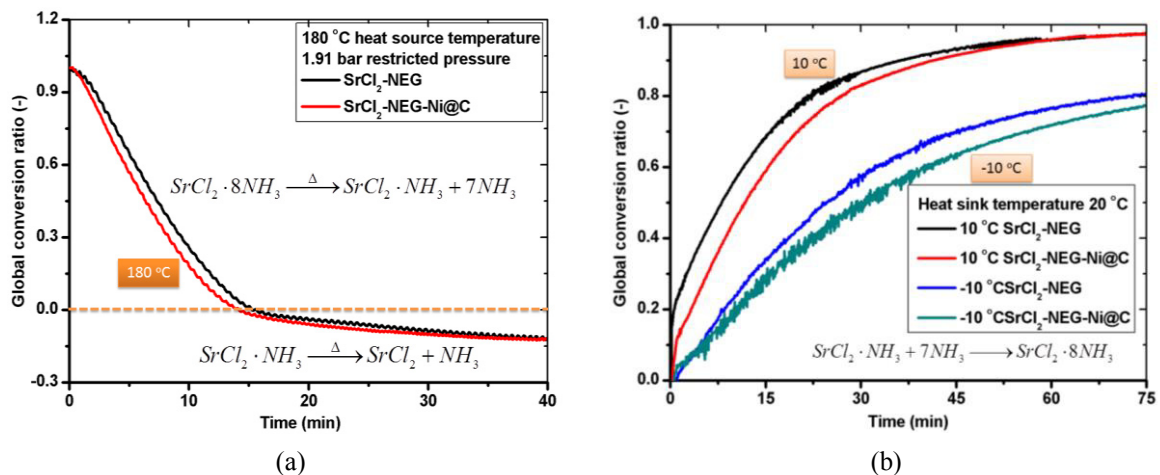


Compared with the adsorption ability of chemical adsorbent- $\text{SrCl}_2$ , the Natural Expanded Graphite and Carbon coated Nickel can only adsorb quite limited ammonia because these two materials will not react with ammonia. And the investigation of the adsorption working pair- $\text{SrCl}_2$  and  $\text{NH}_3$  conducted in this study mainly focus on the first step of chemical reaction as illustrated in equation (2). The global adsorption conversion ratio of the chemisorption composite can be calculated by the following equation, where  $m_{am}(\text{SrCl}_2 \cdot 8\text{NH}_3)$  and  $m_{am}(\text{SrCl}_2 \cdot \text{NH}_3)$  is the gross ammonia inside the condenser / evaporator at the beginning and end of the desorption process, respectively.

$$X = \frac{m_{am}(\text{SrCl}_2 \cdot \text{NH}_3) - m_{am}}{m_{am}(\text{SrCl}_2 \cdot \text{NH}_3) - m_{am}(\text{SrCl}_2 \cdot 8\text{NH}_3)} \quad (4)$$

### 3. Results and discussion

The global conversion ratio of the composite  $\text{SrCl}_2$ -NEG with and without  $\text{Ni@C}$  was compared and analysed as drawn in Figure 3, to investigate the influence of using the  $\text{Ni@C}$  into composite for the chemisorption application. The density of the  $\text{SrCl}_2$  in the adsorbent bed was set at  $300 \text{ kg/m}^3$ .  $\text{Ni@C}$  was used as an additive to improve the heat transfer performance of the composite with the density of  $7.5 \text{ kg/m}^3$ .



**Fig. 3.** Comparison of the performance of the composite adsorbent with and without  $\text{Ni@C}$   
 (a) Desorption performance under 180 °C heat source temperature and 1.91 bar restricted pressure  
 (b) Adsorption performance under heat sink temperature at 20 °C

The desorption performance tests were conducted under the heat source temperature at 180 °C from the oil bath and the restricted pressure of the condenser / evaporator was controlled by the cryostat at 1.91 bar. The relationship between global conversion ratio and time of the composite adsorbent with and without Ni@C is illustrated by the red and black line as shown in Figure 3 (a). It can be found by adding Ni@C into the composite adsorbent the reaction speed can be improved, which means under the same heat source condition the cycle time of a chemisorption system using this novel composite adsorbent can be reduced. And the required overall heat energy for a chemisorption system using this novel composite adsorbent is lower than that of a system without using Ni@C as an additive into adsorbent.

On the other hand, the mass transfer performance of ammonia in the adsorbent is also quite important in chemisorption system. The testing methods for the adsorption performance of the adsorbent conducted were designed to identify the effects of mass transfer performance by adding Ni@C into the composite adsorbent. The top valves V1 and V2 were fully closed before the adsorption test. The adsorbent bed was cooled down by the tape water while the ammonia inside the condenser / evaporator was controlled by the cryostat at desirable temperature. The adsorption performance tests are started until the temperature of the adsorbent bed reaches the environmental temperature and the temperature of the condenser / evaporator is stable. The influence of the heat transfer performance of the adsorbent can therefore be ignored. And the adsorption tests using the designed testing methods can reveal the influence on the mass transfer by adding Ni@C into the adsorbent. The composite adsorbents with and without Ni@C were tested under two driven temperature on the ammonia in condenser /evaporator under the heat sink temperature at 20 °C. Results indicated that by adding the Ni@C into the composite adsorbent the adsorption performance was reduced under the same testing conditions as shown in Figure 3 (b), which means the mass transfer performance of composite adsorbent with Ni@C is poorer than that without Ni@C.

#### 4. Conclusions

In this study, a novel chemisorption composite adsorbent has been developed by adding Carbon coated Nickel into conventional chemical composite adsorbent (SrCl<sub>2</sub>/NEG). The manufacture process of the novel chemisorption composite adsorbent has been reported. The developed mixing methods have been proven as an effective way to evenly distribute Ni@C into the composite, which can potentially improve the overall heat conductivity of the conventional chemical composite. The experimental investigation on the composite adsorbents with and without Ni@C using ammonia as the working fluid was conducted by an adsorption performance testing rig. Results indicated that the novel developed composite adsorbent (SrCl<sub>2</sub>/NEG/Ni@C) requires less heat source energy compared with that of conventional chemical composite adsorbent (SrCl<sub>2</sub>/NEG). The overall energy efficiency of an adsorption system applying the novel composite (SrCl<sub>2</sub>/NEG/Ni@C) can be higher than that of a system using conventional chemical composite adsorbent (SrCl<sub>2</sub>/NEG). Moreover, the cycle time of an adsorption system adding Ni@C into the adsorbent can potentially be reduced. On the other hand, the effect of adding Ni@C into conventional chemical composite adsorbent (SrCl<sub>2</sub>/NEG) on the mass transfer performance were experimentally studied. Results pointed out that the mass transfer performance of SrCl<sub>2</sub>/NEG is better compared with that of SrCl<sub>2</sub>/NEG/Ni@C. Further studies on other candidate Carbon coated Metal nanoparticles added into chemical composite adsorbent can be explored and developed for not only improving the overall sorption performance of the original adsorbent but also overcoming the mass transfer restrictions.



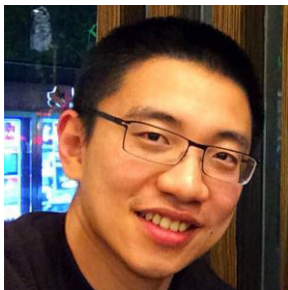
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## Biography



Dr Yiji Lu, born in June 1989, is currently a research associate in Newcastle University. He graduated from Shanghai Jiao Tong University in 2011 for his bachelor degree, he conducted his M.Phil. and Ph.D. in Newcastle University in 2012 and 2016. His Ph.D. program was fully sponsored by EPSRC and was awarded the '2015 Chinese Government Award for Outstanding Self-financed Students Abroad' from China Scholarship Council. His research interests include but not limited to advanced waste heat recovery technologies, engine thermal management, chemisorption cycles and expansion machines for power generation system. He has been regularly invited to review the manuscripts for the scientific journals including *Applied Energy*, *Applied Thermal Engineering*, *Energy* (the international Journal), and *Energy for Sustainable Development*.